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A Computer Model to Predict Empty Body Weight in Cattle from Diet and Animal Characteristics

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ABSTRACT: A computer model was developed to predict empty BW in cattle as a function of diet (forage NDF, physical form of forage [hay vs silage and pasture], proportion of dietary concentrates) and animal (full BW) characteristics. The model was empty BW = full BW * (1 – GFILL), where GFILL is gut fill expressed as a fraction of full BW. An equation obtained from published data (GFILL = .05354 + .329 * NDF) was used to provide a base prediction of GFILL from the fraction of NDF in the forage. Predicted GFILL was then corrected for full BW, physical form of forage, and fraction of concentrates using multiplicative factors obtained from published data. The model was evaluated with data from 11 published experiments. Several breeds of cattle, a wide range of forage types, and diets with 0 to 93% concentrates were represented in these data. Observed values for empty BW were compared to model-predicted values and to values predicted by systems published by the Agricultural Research Council (ARC) and National Research Council (NRC). Sums of squared deviations of predicted values from observed (n = 64) were 3,074, 37,327, and 25,920 for the model, ARC, and NRC systems, respectively. After fitting predicted empty BW values to observed values, proportion of concentrates and forage NDF accounted for a significant ($P < .01$) amount of the residual variation with the ARC and NRC systems, but not for the model. This finding suggests that the model will predict empty BW more accurately than the ARC and NRC systems with diets similar to those used in the evaluation.

Key Words: Simulation Models, Body Weight, Cattle, Diet

Introduction

Equations used to estimate empty BW (EBW) assume that contents of the entire digestive tract (gut fill) are a constant fraction of BW taken after an overnight feed and water shrink (NRC, 1984) or a constant fraction of BW within three discrete dietary classes (ARC, 1980). Using the ARC method, Rohr and Daenicke (1984) found a variation in the ratio of EBW gain to BW gain of .97 to 1.05 for silage-fed steers and of .49 to .80 for hay-fed steers in the experimental data of McCarrick (1966). Gut fill in cattle can represent 5 to 25% of BW depending on the type of diet (Béranger and Robelin, 1978), and both the ARC and NRC methods fail to account for this effect.

Proportion of dietary NDF (Waldo and Smith 1987), proportion of dietary concentrates (Kay et al., 1970), and method of roughage preparation (e.g., hay or silage; McCarrick, 1966) are dietary characteristics that can have a major effect on gut fill. Moulton et al. (1922) reported a decrease in gut fill per unit of BW as BW increased. Waldo and Smith (1987) developed regression equations to predict gut fill per unit of BW from dietary NDF content, and the NRC (1984) reported a regression equation to predict EBW from BW and dietary NE_m. Apart from these references, we are unaware of other published research on a continuous relationship between gut fill and dietary composition. Our objective was to develop a method to convert full BW (FBW) to EBW. To achieve this objective a model was developed to predict gut fill in cattle as a function of forage NDF, physical form of forage DM, proportion of dietary concentrates, and BW of the animal.

3215

Materials and Methods

The variable modeled was the contents of the entire digestive tract (GFILL) as a fraction of BW taken early in the morning before feeding, and with animals having access to feed and water overnight (FBW). Data from published experiments were used to develop relationships between dietary and animal characteristics and GFILL. Dietary characteristics represented in the model were forage NDF, physical form of forage DM, and proportion of dietary concentrates; FBW was the animal characteristic. Published experiments in which effects of these dietary and animal characteristics on GFILL were studied simultaneously could not be found. Analysis of data on cool-season grasses, legumes, and corn silage (Waldo and Smith, 1987) showed that the NDF fraction of these forages accounted for most of the variation in GFILL. We assumed that for similar types of forages this effect would be the same. For warm-season grasses the data were insufficient to support this assumption. An equation was developed from one data set and was used to predict a base GFILL (BASFIL) from the NDF fraction of the forage. Multiplicative correction factors were derived from separate data sets to adjust the predicted BASFIL for the effects of FBW (CFFBW), proportion of dietary concentrates (CFCON), and physical form of forage DM (CFPF).

Hay and silage were the two physical forms of forage DM considered. We further assumed that for the purpose of a physical classification, green pasture was in the same category as silage, and dormant pasture was in the same category as hay. Differences in digestion and passage dynamics between hay and silage were not considered in the model. Plane-of-feeding (level of access to feed, either ad libitum or a percentage of ad libitum) of the same diet and breed type were assumed to have no effect on GFILL (Moulton et al., 1922; Callow, 1961; Crabtree, 1976). The plane-of-feeding assumption is further supported by the work of Bath et al. (1966), who reported mean weights of ruminal contents of 62.3 and 44.1 kg for two heifers that had ad libitum access to feed and mean weights of 64.1 and 50.5 kg after these heifers were restricted to 65% of their requirements for 7 wk. Burrin et al. (1990) gave 16 lambs ad libitum access to feed and restricted the intake of the same diet to maintain BW in another group of 16 lambs. Lambs slaughtered at 0, 7, 14, and 21 d on treatment had GFILL values of .149, .096, .106, and .106 (restricted groups) and .148, .115, .136, and .117 (groups with ad libitum access to feed). These results indicate that differences in GFILL between the two treatments decreased as days on treatment increased. Hence, this assumption may not be valid in the early period, when animals are switched from one plane to another plane of feeding. The entire model is represented in the following equation:

$$GFILL = BASFIL * CFFBW * CFCON * CFPF. \quad [1]$$

Data from Waldo and Smith (1987) were used to obtain a prediction equation for BASFIL. In their study, different types of grass and legume forage were fed in the form of silage with no concentrates (CFCON = 1) and BW ranged from 289 to 364 kg. Assuming that CFPF is 1, we can rearrange Equation [1] to get

$$BASFIL = GFILL/CFFBW.$$

A linear equation (BASFIL = b_0 + b_1 * NDF) was used to fit observed values of BASFIL to the fraction of NDF of the silages in these data. Values for CFFBW used in this equation were calculated with the method outlined below.

The correction factor for FBW was developed from the data of Moulton et al. (1922). In this study, one diet was fed to all the steers after weaning, and animals were slaughtered without fasting over a wide range of FBW. Values of GFILL are plotted against FBW in Figure 1, and an allometric equation,
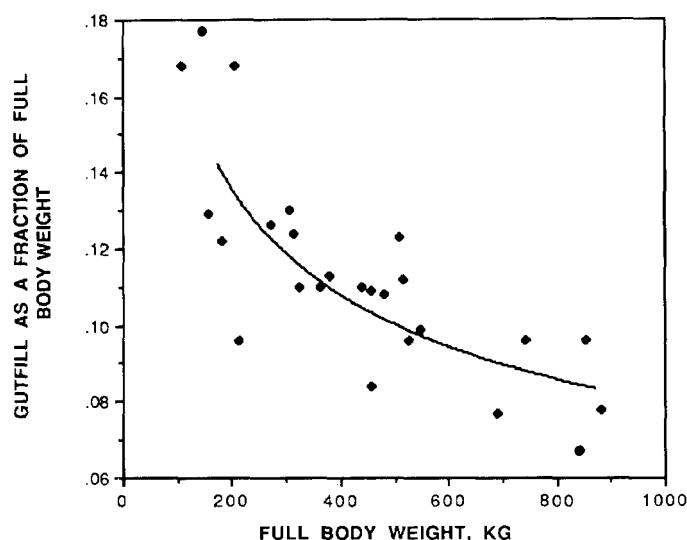
$$GFILL = a * FBW^b$$

Figure 1. Variation in gut fill of cattle as a fraction of full BW (GFILL) vs full BW. Data from Moulton et al. (1922). Equation for the plotted line is GFILL = .788 × full $BW^{-.332}$.

Table 1. Summary of data used to develop correction factor
for fraction of dietary concentrates

| Reference | n | Forage type | Concentrate | | |
			Type	Fraction in diet	Adjustment factor
Kay et al. (1970), Exp. 2[a]	6	Barley straw	Barley/	.87	.325
	6	Barley straw	molasses/	.77	.445
	6	Barley straw	urea	.59	.55
	6	Barley straw		.47	.66
Young and Kauffman (1978)[b]	14	Corn silage	Soybean	.08	.99
	14	Haylage-corn/ silage	meal	.04	1.00
Ferrell and Jenkins (1984)	48	Corn silage	Soybean meal	.1	.96
Kreikemeier et al. (1990)[a]	31	50:50 Alfalfa	Steam-rolled	.95	.37
	32	hay and corn	wheat/	.9	.40
	31	silage	molasses/ corn/fat	.85	.41

[a]Same forage and concentrate used in all treatments.
[b]Same concentrate used in both treatments.

was used to fit these observed GFILL values to FBW. Robelin and Geay (1984) showed that GFILL increased from birth to peak between 200 and 250 kg of FBW, then decreased. Based on these results, we decided to assign CFFBW a value of 1 at 200 kg of FBW; hence, CFFBW was calculated as follows:

$$\begin{aligned} \text{CFFBW} &= \text{GFILL/GFILL}_{200} \\ &= a * \text{FBW}^b/a * 200^b \\ &= (\text{FBW}/200)^b. \end{aligned}$$

Data from McCarrick (1966) on early-cut forage that was made into either hay or silage were used to obtain CFPF. Diets in this study were 100% hay or silage. At an average slaughter weight of 400 kg, gut fill was 42% greater in hay-fed than in silage-fed steers. We decided that CFPF would be 1 for silages, and we obtained a correction factor for hays by dividing the observed GFILL by the predicted GFILL with the hay diet.

Data used to develop CFCON are described in Table 1. Values for GFILL were calculated with no adjustment for concentrates. These predicted GFILL values were then multiplied by the adjustment factors in this table to fit predicted EBW to observed values. Adjustment factors were regressed on linear, quadratic, and cubic terms for the dietary concentrate fraction, weighted by the number of observations. This regression equation was restricted to give a value of 1 for CFCON when the concentrate fraction in the diet was zero, and it was used in the model to predict CFCON. This method assumes that all types of concentrates and forages interact in the same way. However, with very low-quality forages, the response to supplementation with cereals vs high-

protein by-products may be different. In addition, the response to high-protein supplements that differ in ruminal degradability may be different when fed with very low-quality forages.

Data from 11 published experiments with 64 treatment means (Table 2) were used to evaluate the model. Data from late-cut forage (McCarrick, 1966 and Exp. 1 of Kay et al., 1970) were used in model evaluation, and data from early-cut forage (McCarrick, 1966 and Exp. 2 of Kay et al., 1970) were used in model development. For some of the experiments, NDF values of the forages used were not reported, but data on digestibility, crude fiber, and CP were reported. In these cases, NDF values were estimated from similar types of forages using compositional data published on the forage in tables of feed composition (NRC, 1989). The GFILL was predicted with the model for each of the treatments in these 11 experiments, and EBW was calculated from GFILL. Observed values for EBW were compared to values predicted with the model and values predicted with the following equations:

$$\text{EBW} = \text{FBW}/1.09 - a \qquad \text{(ARC, 1980)}$$

where a = 4 for high-concentrate diets, 14 for mixed diets, and 25 for long, dried roughage:

$$\text{EBW} = .891 * (\text{Shrunk BW}) \qquad \text{(NRC, 1984)}.$$

The accuracy with which these three systems (model; ARC, 1980; and NRC, 1984) predicted EBW was evaluated by calculating the sum of squared deviations of predicted from observed values for EBW and by regressing the observed EBW values on the predicted values (Harrison, 1990).
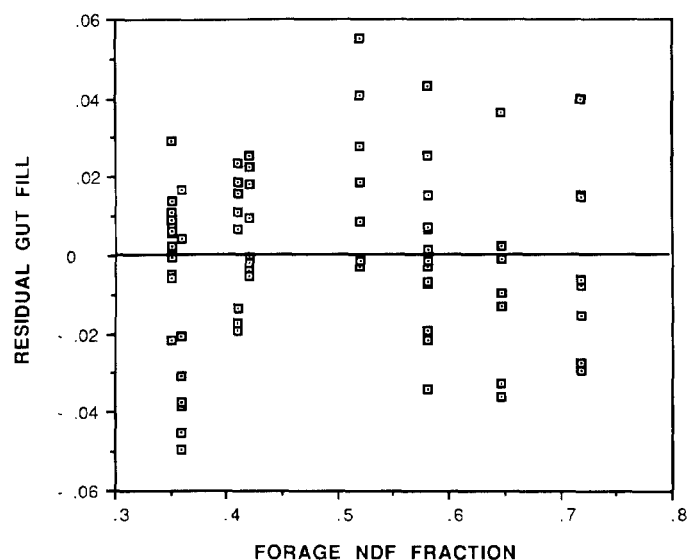
Figure 2. Relationship between residual gut fill and forage NDF fraction.

Results and Discussion

The prediction equation (individual animal data from Waldo and Smith, 1987) from the regression of BASFIL on the fraction of forage NDF in the diet was as follows:

$$BASFIL = .05354 + .329 * NDF$$
$$(R^2 = .80, n = 79).$$

Residual values of BASFIL are plotted against fraction of forage NDF in Figure 2. These residuals show no systematic bias in using this equation to predict BASFIL.

The regression equation (individual animal data from Moulton et al., 1922) of GFILL on FBW was as follows:

$$GFILL = .788 * FBW^{-.332} (R^2 = .662, n = 25).$$

This regression line is plotted in Figure 1, along with the observed data points. With this equation, CFFBW was calculated as follows:

$$CFFBW = (FBW/200)^{-.332}.$$

The equation used to predict GFILL from the data on early-cut forage from McCarrick (1966) was GFILL = BASFIL * CFFBW. This data set was four treatment means (two for silage and two for hay diets) with 10 steers per treatment. A predicted GFILL value of .13 was obtained for both silage diets vs the observed value of .12 for both diets. This supports a value of 1 for CFPF when the forage DM is in the form of silage. Both the hay diets had observed and predicted GFILL values of

.18 and .13, respectively. In this case the observed value was about 1.35-times greater than predicted. Based on these results, the value of CFPF was set at 1 when the forage DM was in the form of silage and at 1.35 when the forage DM was in the form of hay.

The regression equation to predict CFCON from the fraction of dietary concentrates (X) was as follows:

$$CFCON = 1.0 - .246 * X - 1.481 * X^2 + 1.107 * X^3$$
$$(n = 10, R^2 = .999, S_{y \cdot x} = .071).$$

Predicted values for EBW calculated with the model (FBW – predicted GFILL * FBW) and with the ARC (1980) and NRC (1984) equations are compared in Table 3 with observed data on FBW and EBW. Except for the treatments of Gibb and Baker (1987, 1989) and Brown and Johnson (1991) with ammoniated hay, the model predictions of EBW were close to the observed values, whereas, in most cases, the ARC (1980) and the NRC (1984) equations tended to predict higher EBW values than those observed. The sum of the squared deviations of the EBW values predicted with the model and with the ARC (1980) and NRC (1984) equations from the observed EBW values were 10,071, 37,327, and 25,920, respectively.

With reference to the Gibb and Baker (1987, 1989) and Brown and Johnson (1991) data, these results suggest that classification of ammoniated hay as hay was incorrect because the problem with the model in this case seemed to be with the correction factor for the physical form of the forage DM. This factor was developed from the data of McCarrick (1966), who noted an increase in GFILL of about 40% for hay compared with silage prepared from the same material. In the data of Gibb and Baker (1987), although there was a 25% increase in GFILL with a 100% perennial ryegrass ammoniated hay diet (65% NDF) compared with 100% perennial ryegrass silage diet (51.3% NDF), this increase could be accounted for by the greater NDF percentage of the hay diet. Data from Gibb and Baker (1989) in which perennial ryegrass hay treated with ammonia or untreated was fed showed a 35% increase in GFILL for the untreated hay compared with the treated hay. This result supports the correction factor for the untreated hay, but not for the treated hay. These results suggest that ammoniated hay should be classified as silage; hence, the CFPF should be 1 for this type of hay.

The model with CFPF equal to 1 was used to predict GFILL for the treatments in which ammoniated hay was used in the experiments of Gibb and Baker (1987, 1989) and Brown and Johnson (1991). The EBW values calculated from the

predicted GFILL are given in parentheses in Table 3 for these treatments. The sum of the squared deviations of the 64 EBW treatment means predicted with the model from the observed values decreased from 10,071 to 3,074 with the new predicted EBW values for the 12 treatments in which ammoniated hay was fed. The results for the data from Brown and Johnson (1991) showed no consistent trends in model predictions of EBW when compared to observed values. Although no data on warm-season grasses were used in model development, these results suggest that the model may be applicable in situations in which these grasses are the forage source.

Results of the regressions of observed EBW treatment means (independent variable) on the treatment means predicted with the model, ARC (1980), and NRC (1984), weighted by the number of observations per treatment, are presented in Table 4. Slopes of the three regressions were all close to 1; however, the negative intercepts for the ARC (1980) and the NRC (1984) systems indicate that these systems consistently overpredicted the observed values. Deviations of model predictions of EBW from observed values were negative, zero, and positive for observed EBW values > 355, equal to 355, and < 355 kg. These regression results suggest that predictions of EBW with the

Table 2. Summary of data from 64 treatments in 11 published experiments used to evaluate the model

Reference	No. of treatments	n	Forage Name	Type	NDF, %	Concentrate fraction in diet
Béranger and Robelin (1978)	1	14	Alfalfa	Hay	40.0[a]	0
	1	28	Alfalfa	Hay	40.0[a]	0
	1	12	Alfalfa	Hay	40.0[a]	0
Brown and Johnson (1991)	1	18	Stargrass	Hay	81.7	0
	2	36	Stargrass	Hay	81.7	.23
	1	16	Stargrass	Hay	75.2	0
	2	32	Stargrass	Hay	75.2	.16
Daenicke et al. (1982)	2	24	Maize	Silage	51.0[a]	.38
Gibb and Baker (1987)	2	12	Perennial ryegrass	Silage	51.3	0
	2	12	Perennial ryegrass	Hay	65.0	0
	4	24	Perennial ryegrass	Pasture	65.0[a]	0
Gibb and Baker (1989)	1	6	Perennial ryegrass	Hay	66.4	0
	1	6	Perennial ryegrass	Hay	66.4	.2
	1	6	Perennial ryegrass	Hay	66.4	.4
	1	6	Perennial ryegrass	Hay	66.4	.45
	1	6	Perennial ryegrass	Hay	66.0	0
	1	6	Perennial ryegrass	Hay	66.0	.44
	6	36	Perennial ryegrass/ White clover	Pasture	66.0[a]	0
Kay et al. (1970) Exp. 1	1	6	Barley	Straw	80.0[a]	.87
	1	6	Barley	Straw	80.0[a]	.77
	1	6	Barley	Straw	80.0[a]	.59
	1	6	Barley	Straw	80.0[a]	.47
McCarrick (1966) Late-cut forage	2	20	Perennial ryegrass	Hay	42.0[a]	0
	2	20	Perennial ryegrass	Silage	42.0[a]	0
McCullough (1970)	1	12	Mixed sward[b]	Hay	66.0[a]	.95
	1	12	Mixed sward	Hay	66.0[a]	.8
	1	12	Mixed sward	Hay	66.0[a]	.6
Murray et al. (1974)	4	11	Oat	Straw	80.0[a]	.88
	4	9	Oat	Straw	80.0[a]	.88
	4	9	Oat	Straw	80.0[a]	.83
Thomas et al. (1988)	1	10	Perennial ryegrass	Silage	58.5	0
	1	10	Perennial ryegrass	Silage	44.1	0
	1	10	Perennial ryegrass	Silage	58.5	.28
	1	10	Perennial ryegrass	Silage	58.5	.56
Veira et al. (1988)	1	8	Mixed sward[c]	Silage	51.9	0
	2	8	Mixed sward	Silage	51.9	.08
	1	8	Mixed sward	Silage	49.7	0
	2	8	Mixed sward	Silage	49.7	.07

[a]Estimated from similar types of forages (NRC, 1989), using reported data on digestibility, CP, and crude fiber.
[b]Name of forage was not given.
[c]Timothy, red fescue, Canada blue grass, switch grass, and birdsfoot trefoil.

Table 3. Unfasted body weight (FBW) and predicted empty body weight (EBW) values from the model, ARC (1980), and NRC (1984) vs observed values

Reference	FBW	EBW, kg			
		Observed	Model	ARC	NRC
Béranger and Robelin	600	497	497	525	513
(1978)	545	448	448	475	466
	439	364	355	378	376
Brown and Johnson	450	342	302(340)[a]	388	385
(1991)	481	387	345(380)	427	411
	495	386	357(393)	440	423
	479	357	335(372)	415	410
	487	375	352(387)	433	417
	496	384	358(394)	441	424
Daenicke et al.	557	481	492	497	477
(1982)	556	487	490	496	475
Gibb and Baker	184	141	142	144	157
(1987)	202	152	158	161	173
	185	130	118(134)[a]	144	158
	193	138	125(141)	152	165
	319	251	246	267	273
	333	261	259	281	285
	305	236	235	255	261
	310	240	239	260	265
Gibb and Baker	160	122	98(114)[a]	122	137
(1989)	217	173	166(178)	185	186
	178	131	112(129)	138	152
	222	180	166(179)	190	190
	172	117	106	133	147
	218	167	164	186	186
	329	256	255	277	281
	342	269	266	289	293
	335	259	260	282	287
	371	293	291	315	317
	329	259	255	277	281
	365	286	286	310	312
Kay et al. (1970),	403	361	349	365	344
Exp. 2	397	354	338	361	340
	400	336	323	353	342
	398	315	307	351	340
McCarrick (1966)	377	324	319	332	322
Late-cut forage	381	326	322	335	326
	398	320	317	340	340
	376	299	298	320	322
McCullough	398	351	355	361	341
(1970)	395	347	346	358	338
	394	336	329	347	337
Murray et al.	330	280	283	299	282
(1974)	363	301	313	329	310
	401	349	349	364	343
	441	387	385	401	377
	332	284	286	301	284
	362	316	313	328	310
	400	345	348	363	342
	440	390	384	400	376
	329	279	281	298	281
	364	299	312	330	311
	400	346	344	363	342
	439	366	379	399	376
Thomas et al	354	282	283	311	303
(1988)	393	335	331	347	336
	382	316	319	336	327
	408	346	361	360	349
Veira et al.	361	302	295	317	309
(1988)	386	322	319	340	330
	420	346	349	371	359
	405	333	336	358	346
	409	339	341	361	350
	444	356	373	393	380

[a]Ammoniated hay was used in these treatments, and values in parentheses were obtained by reclassifying the hay as silage.

Table 4. Regression[a] of observed on predicted empty BW (kilograms) treatment means weighted by number of observations per treatment

System	n	b_0	b_1	$S_{y \cdot x}$	R^2
Model	64	7.36 (3.02)[b]	.976 (.008)	19.74	.995
ARC (1980)	64	−9.35 (6.17)	.96 (.016)	38.32	.983
NRC (1984)	64	−24.89 (8.39)	1.03 (.023)	49.70	.971

[a]Model: observed empty BW $= b_0 + b_1$ * predicted empty BW.

[b]Values in parentheses are standard errors.

ARC (1980) and NRC (1984) systems, when adjusted with the appropriate regression equation, may yield predicted EBW values that are closer to observed. It is possible that these adjusted predictions of EBW may provide a more accurate estimate of EBW than the model. This hypothesis was tested with the following linear model: Observed EBW $= b_0 + b_1$ (predicted EBW) $+ b_2$ (CONF) $+ b_3$ (FNDF), where **CONF** is the fraction of concentrates in the diet and **FNDF** is the fraction of NDF in the forage. Predicted EBW used in separate runs of this model were 1) predicted EBW with the model described in this paper, 2) predicted EBW with the ARC (1980) equation corrected with the regression equation in Table 4, and 3) predicted EBW with the NRC (1984) equation corrected with the regression equation in Table 4. All treatment means were weighted by the number of observations per treatment in these runs. Results of this analysis are shown in Table 5. Both CONF and FNDF failed to account for a significant amount of the residual variation after fitting model predictions of EBW to the observed values, whereas the opposite was true for the ARC (1980) and NRC (1984) systems. These results indicate that even after adjusting the ARC (1980) and NRC (1984) predictions of EBW, these systems

would still significantly over- and underpredict EBW for high-concentrate diets and for diets in which high-NDF forages are used, respectively. The inaccuracy of the NRC (1984) equation in predicting EBW is probably a result of the fact that this equation was based on data from diets composed largely of concentrates.

Conclusions

Our model to predict EBW in cattle is simple and easy to use in practical applications because the only inputs needed are forage NDF, physical form of forage DM (hay, silage, or pasture), fraction of concentrates in the diet, and FBW of the animal. The evaluation results using 11 independent sets of published data showed that the model accurately predicted ($R^2 = .99$) observed EBW values. In cases in which forages are treated (e.g., ammoniated hay) the model was not very accurate, but reclassifying treated hay as silage resulted in more accurate model predictions of EBW. A comparison of the model with the ARC (1980) and NRC (1984) systems showed that the model was more accurate in predicting EBW, even after adjusting the predictions of EBW from the ARC and NRC systems. However, if either the ARC (1980) or NRC (1984) system of predicting EBW is used, it is recommended that the predictions be adjusted by the regression equations given in Table 4.

The model was developed with data on cool-season grasses, legumes, and corn silage, and it has not been fully tested with warm-season grasses; however, preliminary results with stargrass showed no inconsistencies. It is possible that the correction factor for concentrates (CFCON) may not be appropriate in cases in which very-low-quality forages are supplemented with either cereal or high-protein by-products or protein supplements that differ in ruminal degradability. As

Table 5. Percentages of residual variation in observed empty BW treatment means accounted for by fraction of concentrates in the diet (CONF) and percentage of NDF in the forage (FNDF) after fitting observed empty BW (kilograms) to predicted empty BW treatment means, weighted by number of observations per treatment[a]

System	Residual variation accounted for, %		Parameter value	
	CONF	FNDF	b_2	b_3
Model	.05	1.4	2.23	−.06
ARC (1980)	13.04**	49.22**	33.74**	−.68**
NRC (1984)	31.47**	68.1**	56.21**	−.92**

[a]Model: observed empty BW $= b_0 + b_1$ (predicted empty BW) $+ b_2$ (CONF) $+ b_3$ (FNDF).

**$P < .01$, where P is the probability of rejecting the null hypothesis when it is, in fact, true.

more data become available, the model needs to be tested under these experimental conditions. Data used to develop and evaluate the model were obtained from animals that were on a specific plane of feeding for > 3 wk, and model predictions of EBW may be inaccurate in the early period when animals are switched from one plane of feeding to another. In addition, data on FBW used to develop and evaluate the model represent unfasted FBW taken in the morning on weaned animals; hence, the model should be used with weaned animals.

Implications

We developed a model to predict gut fill in cattle and used the predicted gut fill to estimate empty body weight. Model inputs are dietary characteristics that can be obtained from routine forage analyses and unfasted body weight. This model was found to be more accurate than the methods that are in current use. In addition, the model is simple, and it can easily be incorporated in diet formulation programs and systems models of cattle production.

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